French popularizers of science, which has made them masters of their art.

The above-named volumes are three of a number of similar treatises which have lately appeared. The appreciation of the beautiful and generally interesting in Nature must always precede the study of the more useful and special, and it is the highest function of works like the present to awaken this preparatory appreciation. Of such works those are the most valuable whose authors can claim a sound elementary knowledge of the facts with which they deal, and a familiarity with current research. Only on these terms can a popular natural history rise above the level of the too well-known type, in which the scissors supply the knowledge and the paste usurps the place of the co-ordinating intellect. G. B. H.

A GENERAL FORMULA FOR THE FLOW OF WATER.

A General Formula for the Uniform Flow of Water in Rivers and other Channels. By E. Ganguillet and W. R. Kutter. Translated from the German by Rudolph Hering and John C. Trautwine, Jun. (London: Macmillan and Co., 1889.)

THE general formula devised by Messrs. Ganguillet and Kutter for caculating the flow of water in both large and small channels, under varied conditions, was brought under the notice of English-speaking engineers by the publication, in 1876, of a translation by Mr. Jackson of some articles on the subject written by Mr. Kutter, which appeared in the *Journal der Cultur-Ingenieur* in 1870. This translation, however, was not authorized by Mr. Kutter, and contained some incomplete tables inserted by Mr. Kutter in his articles at the request of a friend. The present volume is a translation of the second edition of the treatise on the formula, written by Messrs. Ganguillet and Kutter, engineers in Berne, who have added a preface to the translation. Mr. Kutter died whilst this translation was in progress; and a short memoir of him, with a list of his works, is appended to the translators' preface.

The book commences with an historical sketch of the attempts to arrive at a formula for the flow of water in open channels; and the insufficiency of the earlier formulæ is pointed out. The investigations of Messrs. Darcy and Bazin, and the gaugings of the Mississippi by Messrs. Humphreys and Abbot, are then concisely described, and the formulæ which they deduced from the results of their experiments are given, the history of the subject, in a brief form, being thus brought down to the period at which Messrs. Ganguillet and Kutter commenced their investigations. This forms a sort of introduction to the account of the conception and development of the general formula, of which the various steps are described in detail. The modifications for various amounts of roughness are classified; and, finally, the formula is tested by the comparison of its results with a number of gaugings under very different conditions; and these results indicate, in considerably the greater number of cases, a closer approximation to the actual measurements than those obtained with the formulæ of either Humphreys and Abbot, or Bazin. A supplement gives a more direct derivation of the formula for mathematical readers; and the appendices contain numerous tables giving the flow of water in pipes under pressure, as well as in open channels, for practical use in English measures, derived from the formula, and also a diagram for the graphical determination of the values of the factors in the formula, adapted to English measures by the translators.

Most of the hydraulicians who had investigated the question before Darcy and Bazin, such as De Prony, Dubnat, Eytelwein, D'Aubuisson, Downing, and others, agreed in adopting a formula of the form $V = c\sqrt{RS}$, of which Brahms and Chezy are said to have been the authors in the latter half of the last century, in which V is the velocity, R the hydraulic radius, and S the slope. Different values were assigned to the factor c by the various investigators; but it was always regarded as a constant, applicable to any sized stream in most cases, to any slope, and to any state of the bed. Mr. Darcy was the first who directed attention to the influence the condition of the sides of channels and pipes exercised on the discharge; and he instituted a series of experiments, carried out after his death by Mr. Bazin, by which the flow of water in regular uniform channels, under different conditions of slope, form, and roughness of bed, was measured by careful gaugings and gauge-tubes. A few years previously, Messrs. Humphreys and Abbot had carried out their well-known gaugings of the flow of the Mississippi by means of double floats, and deduced a formula for the results obtained. Messrs. Ganguillet and Kutter found that the formula derived from the Mississippi experiments, relating to a large river with a very slight slope, was not applicable to the small streams with steep slopes of which they measured the flow in Switzerland, and also that Mr. Bazin's formula was not suitable, in its original form, for large rivers with irregular beds. This led Messrs. Ganguillet and Kutter to search for a formula applicable to very different slopes and sizes of channel, and adaptable to various conditions of bed. They took as the basis of their formula the various experimental results obtained in France and America, together with their own independent observations on channels with steep slopes, so as to include the extreme varieties of flow within the range of a single formula. Starting from Mr. Bazin's formula, $V = \sqrt{\dfrac{RS}{a + \dfrac{\beta}{R}}}$, where $c = \sqrt{\dfrac{1}{a + \dfrac{\beta}{R}}}$, they eventually found it expedient to express the value of c in the form $\dfrac{y}{1 + \dfrac{x}{\sqrt{R}}}$, in which, though they at first assumed y and x to be constant for any given state of bed, they finally modified them to expressions varying with the slope. The alterations in the formula were effected by aid of graphical representations of the various sets of gaugings. It was found, in investigating the various experimental results, that the factor c varied generally with the slope; but a somewhat anomalous result was also noted—namely, that whereas in the Mississippi observations c increased with a decrease in the slope, it on the contrary decreased with a decrease of slope in the gaugings of small channels, unless the wetted

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perimeter was very rough. This change in the variation of c with relation to the slope was found to depend upon the hydraulic radius being greater or less than 3·281 feet; so that c becomes independent of the change in slope when R approximates to this value, though the actual value of R at which the modification occurs varies with the degree of roughness of the channel. This result is attributed to the conflicting currents and eddies in large rivers having irregular beds, or in small channels with very rough beds, which are intensified by an increase in the slope; whereas, in small streams flowing in confined channels with smooth beds, an increased velocity tends to dissipate retarding lateral movements. A preliminary form adopted for the value of c was $\dfrac{a + \frac{l}{n}}{1 + \frac{an}{\sqrt{R}}}$, where $a + \frac{l}{n}$ replaces y in the original formula, and $an = x$, or $x = ny - l$, in which a is a constant with value 41·66 in English measures; l is another constant, equal to $\sqrt{R}$ when R has the special value 3·281 referred to above, and therefore 1·811; and n is the coefficient of roughness, varying, according to the state of the channel, from 0·009 to 0·040. The above value of c suffices for the flow in pipes and other small channels with steep slopes, owing to the small influence of a variation of slope on the coefficient c in such cases; but for ordinary channels allowance has to be made for variations in slope, necessitating the introduction of another variable factor into the expression for c. The final shape given to the value of c by Messrs. Ganguillet and Kutter, in their general formula, was $\dfrac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right)\frac{n}{\sqrt{R}}}$, where $m = 0{\cdot}0028075$, for English measures, is a constant of a hyperbola employed in constructing the formula. The general formula, accordingly, became, for English measures—

$$V = \frac{\frac{1{\cdot}811}{n} + 41{\cdot}6 + \frac{0{\cdot}00281}{S}}{1 + \left(41{\cdot}6 + \frac{0{\cdot}00281}{S}\right)\frac{n}{\sqrt{R}}}\sqrt{RS},$$

where V is the mean velocity in feet per second, which multiplied by the cross-section would give the discharge in cubic feet per second, and S is the actual slope.

The main interest of the book consists in the clear exposition of the several steps by which the formula was reached; and even if at some future time, by the aid of fresh observations and more accurate experiments, the formula should be superseded by a more comprehensive and exact one, the merit of this work as an elaborate scientific investigation for a general empirical formula must always remain; and the book would deserve to be consulted on this ground alone. The formula depends entirely upon the exactness of the observations upon which it has been based. Mr. Révy has questioned the accuracy of the Mississippi experiments, owing to the use of double floats; and if fresh investigations should establish the inaccuracy of any of the observations made use of, or if further experiments should extend the scope of the inquiry, or bring new facts to light, a modified formula will be required. The authors, however, of the formula do not regard it as final or complete, nor do they claim for it any mathematical precision; they only consider that it agrees more closely than any previous formula with the results of recorded observations. The formula has naturally been objected to on account of its complicated appearance; but the variation due to change of slope renders this inevitable; and it has been seen that a simpler formula may be adopted for pipes, and small channels with steep slopes; and, moreover, graphical methods and tables might simplify the calculations. At the close of last year, Mr. Robert Manning, Engineer to the Board of Works in Dublin, presented a new formula to the Institution of Civil Engineers of Ireland, which, in its general form, is hardly less complicated than that of Messrs. Ganguillet and Kutter. This formula is

$$V = n\sqrt{Sg}\left\{R^{\frac{1}{2}} + \frac{0{\cdot}22}{m^{\frac{1}{2}}}(R - 0{\cdot}15m)\right\},$$

where n is the coefficient of roughness, g the force of gravity, and m the height of the barometric column of mercury. Mr. Manning puts it forward as simpler and better than the other, and claims for it, in a simplified form, a closer approximation to the mean of the results of seven of the best known formulæ than any other. Actual observations, however, form a surer basis upon which to establish a general formula than the results of previous formulæ; and it is upon a close concordance with very varied and accurate observations that any general formula must claim acceptance. Whatever position may in the future be assigned to the formula of Messrs. Ganguillet and Kutter, their work marks a notable step in advance, and must rank with the researches of Messrs. Darcy and Bazin, and Messrs. Humphreys and Abbot, as a record of important hydraulic investigations; and the translators have performed a valuable service in placing clearly before English readers the successive steps by which this general formula has been established.

THE COMPASS ON BOARD.

Der Kompass an Bord: Ein Handbuch für Führer von eisernen Schiffen. Herausgegeben von der Direktion der Deutschen Seewarte. (Hamburg: L. Friederichsen and Co., 1889.)

THE important subject of the magnetism of iron ships and the resulting deviations of their compasses, has, during the last fifty years, received marked attention in England from eminent men of science, attended with most valuable results for the safe navigation of our Royal and mercantile navies.

During the last thirteen years this same subject has been one of continuous inquiry at the German Naval Observatory in Hamburg, and papers have been published from time to time in the annual report of that institution, showing what had been accomplished. Combining the results of this work with those obtained from the extensive literature chiefly produced in England, Dr. Neumayer, the Director of the Observatory, has compiled the present work for the use of officers commanding the iron ships of the German mercantile navy.

Of the six chapters into which the work is divided, the first is devoted to information on the magnetism of iron

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